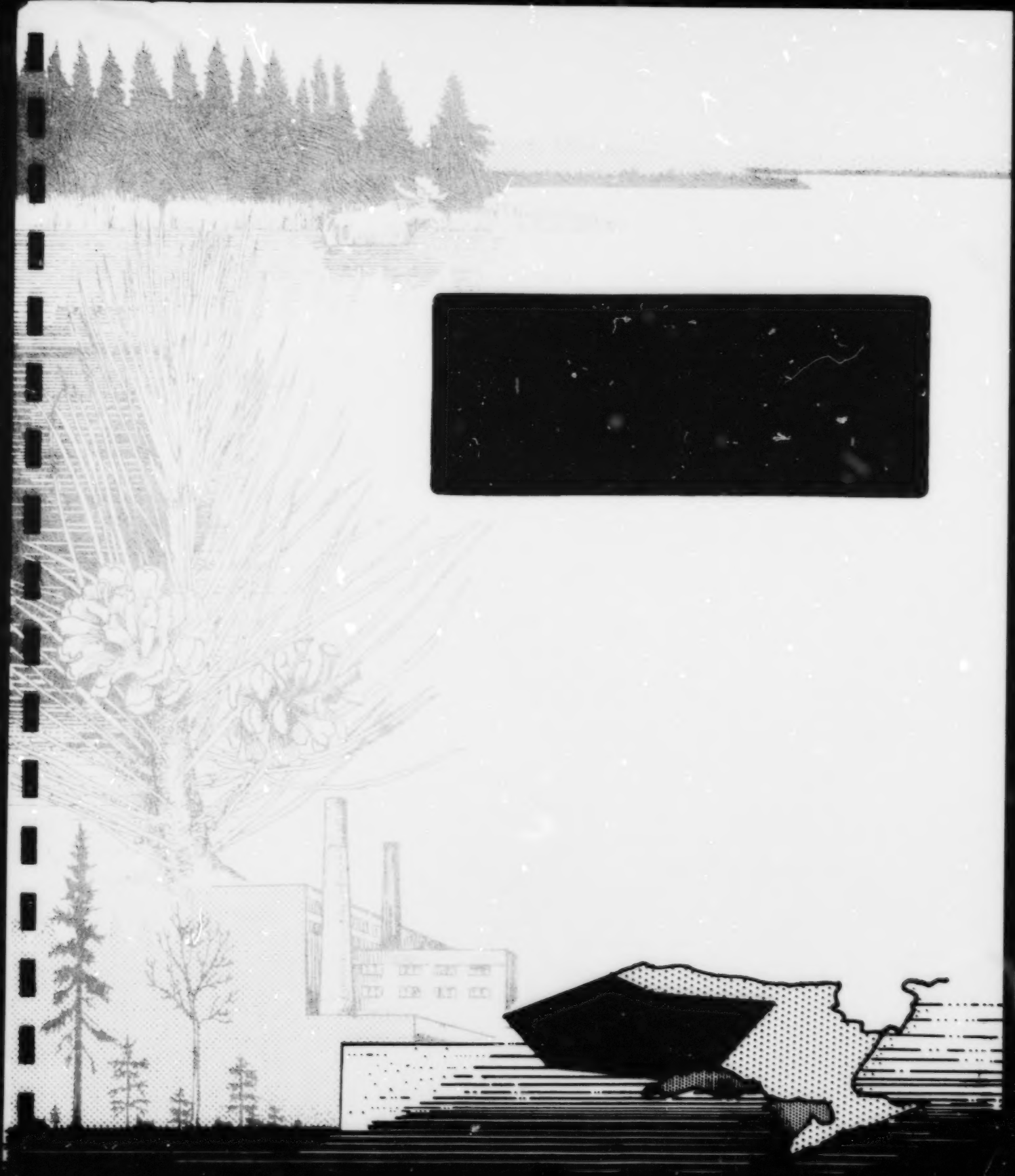

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NORTHWESTERN ONTARIO FOREST TECHNOLOGY DEVELOPMENT UNIT

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THE EXTENT AND NATURE OF SEEDED JACK PINE CLUMPING FOLLOWING DISTURBANCE IN NORTHWESTERN ONTARIO

by

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ABSTRACT

Thirty-one jack pine (*Pinus banksiana* Lamb.) stands, 2 to 20-years-old, were sampled in Northwestern Ontario. These stands represented six different seeding methods: (1) hand seeded with shelter cones, (2) hand seeded, no shelter cones, (3) Bracke spot seeding, (4) scarification of slash, (5) aerial seeding, (6) wildfire. These seeding methods were compared for total density, density of clumps, ratio of clumped seedlings to total seedlings (clumping index (CI)) and a measure of non-random spatial distribution (Pielou's Index). Density and CI were found to be significantly different between seeding methods based upon ANOVA results. Spot seeding (hand and Bracke methods) produced distinctly clumped cutovers compared to the other methods while wildfire areas showed three times the density of the spot seeded sites (21,000 stems/ha vs. 7,000 stems/ha). All methods produced aggregated distributions of plants based upon Pielou's Index. The utility of this index in effectively describing "tight clumps" is questionable.

Comparisons of dominant trees within a clump to randomly selected free growing trees showed the clumped trees to exhibit superior form and height growth at the juvenile stage. Diameter growth was not significantly different between the two types of sample tree populations. Long-term effects of juvenile clumping are difficult to predict. However, it seems unlikely that serious adverse effects upon tree growth and form are probable. Uniform spacing of jack pine at later stages of stand development may be more cost effective than incurring costs to achieve uniform spacing at the time of stand establishment.

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INTRODUCTION

Planting trees in Ontario has increased from 29,000 hectares annually in the 1970s to 50,000-60,000 hectares annually with the financing of the province's Forest Management Agreements (Kuhnke 1989). However, unreliable delivery of quality growing stock and the high cost of planting programs are causing serious problems, and planting levels are now capped. Ontario is considering a strategy of larger investments on strategic or prime sites which may limit funds available to intensively treat the majority of remaining sites.

Low cost regeneration systems will be required for a greater portion of the land base. Canada's uniquely low opportunity cost for land and relatively slow-growing climate make extensive low cost per hectare silvicultural investments a realistic strategy to maintain leadership in the world supply of wood fibre (Sedjo 1986). For these reasons, Canada and Ontario would benefit from research into low cost silvicultural systems.

Jack pine (*Pinus banksiana* Lamb.) naturally regenerates from seed released from cones in residual standing trees following wildfire. Cones will also release seed from slash left after logging operations. Site preparation techniques often attempt to redistribute the slash and expose mineral soil to encourage regeneration from seed. Broadcast aerial applications of processed seed onto site-prepared cutovers is a common practice in Ontario. The spatial pattern of seedlings growing from the above conditions is related to topography, distribution of suitable seedbeds and seed dispersal patterns.

Direct seeding concurrent to site preparation is less wasteful of seed and is thought to distribute seed more evenly across the treated area because seed is targeted to drop on specific seed spots (Parker 1972, Sidders 1985). Hand seeding with shelter cones has shown some excellent results with boreal conifer species and works well with jack pine (Dominy and Wood 1986). Unfortunately, successful stocking requires more than one seed per spot. Few seed delivery devices can singulate seed even if one seed per spot were adequate for certain situations.

Foresters have noted that seedlings that emerge from cones in slash, hand placed shelter cones and direct seeded site preparation form distinctive clumps. Many assume stands from wildfire are not clumped. Variable depths of duff and different heat intensities may create seed beds in a clumped pattern but this has not been clearly documented. Although most foresters agree that the root systems of seed origin jack pine are generally superior to those of planted stock, concern over wood quality, pathogen susceptibility and slower stem caliper growth from the dense "clumping effect" tends to limit the expansion of low cost silvicultural systems which rely on jack pine seeding.

Important questions arise from the observations of these clumping patterns. Does clumping have negative effects upon stem quality and stand growth? Stiell (1982) suggests that uniform spacing, where trees are equivalently distant from one another, is necessary to maximize site utilization. But are the high costs of

site preparation, planting and thinning needed to achieve this uniform pattern justified by the gains in stand growth?

The Northwestern Ontario Forest Technology Development Unit of the Ontario Ministry of Natural Resources (OMNR) contracted KBM Forestry Consultants Inc. to undertake an exploratory investigation of clumping in juvenile jack pine to address the first of the above questions. The strategy chosen was to compare the structure of artificially established stands with the structure of natural (fire established) stands. This investigation provides:

1. A definition of clumping of juvenile jack pine in units that can be readily recognized and measured in the field.
2. A measure of the prevalence of the clumping condition and its relationship to stand origin and age.
3. A comparison of the growth and development of free growing to clumped trees.

METHODS

Sample Areas

The study area included most of the commercial and accessible portions of the boreal forest region in Northwestern Ontario (Rowe 1972). Topography and drainage are controlled by pre-Cambrian bedrock with thin layers of glacial deposits of varying depths forming the soil substrate. Jack pine stands originating from seed following clear cut or wildfire disturbance are most commonly associated with the more dry, coarse-textured soils (Fowells 1965).

Recently burned or cut areas (2 to 20-year-old) supporting pure seed origin jack pine stands were selected by OMNR staff as candidate sample areas from their silvicultural records. An even representation of common seeding methods was sought. Sample areas were then selected if they had a minimum stocking level of 60% (Chaudhry 1981) and suitable road access. The stocking requirement limited the scope of the study to successful treatments and helped reduce sample variance.

All but one of the sample areas was in Northwestern Ontario (Figure 1). Sample area #4 near the town of Manitouwadge lies well to the east of the main study area. Observations regarding the persistence of jack pine clumping were of interest in selecting this area because it was a 20-year-old representative of the Bracke spot seeding method.

Table 1 lists the seeding method and the year in which seed was sown. Seeding methods are broadly grouped by seed dispersal pattern as either spot or broadcast. Hand shelter seeding methods involve placing seed onto mineral soil seed spots beneath open-ended plastic shelters that resemble inverted drinking cups (Dominy and Wood 1986, Putman and Zasada 1986, Campbell and Baker 1989, Van Damme 1989). Bracke seeding is accomplished by dropping seed from a seed hopper concurrent with the normal site preparation action of the Bracke scarifier (Parker 1972, Smith 1980). Hand spot seeding is infrequently practiced. Seed is dropped by sowers onto

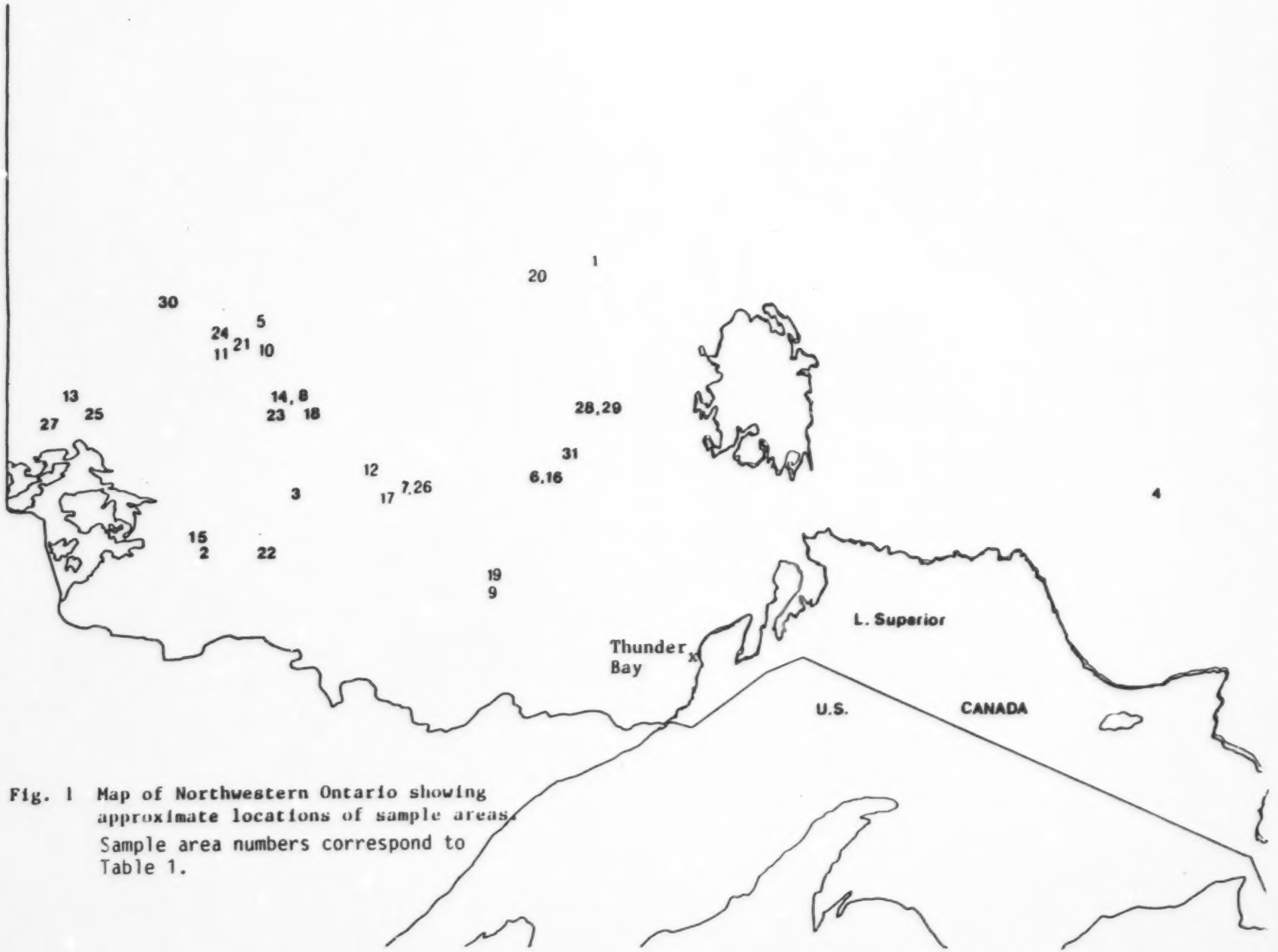

Fig. 1 Map of Northwestern Ontario showing approximate locations of sample areas. Sample area numbers correspond to Table 1.

Table 1. List of sample areas by OMNR district and silvicultural treatment.

Sample Area #	Seed Dispersal Method	Seed Dispersal Pattern	Site Prep Pattern	Year of Estab.	OMNR District
1	Shelter Cones	Spot	Cont*(B&C)**	1985	Sioux Lookout
2	Shelter Cones	Spot	NIL	1987	Fort Frances
3	Shelter Cones	Spot	Cont(Trench)	1987	Dryden
4	Bracke	Spot	Patch	1971	Manitouwadge
5	Bracke	Spot	Patch	1978	Red Lake
6	Bracke	Spot	Patch	1984	Thunder Bay
7	Bracke	Spot	Patch	1985	Ignace
8	Hand	Spot	NIL	1970	Dryden
9	Hand	Spot	Cont(Blade)	1977	Atikokan
10	Hand	Spot	Cont(B&C)	1978	Red Lake
11	Hand	Spot	NIL	1985	Red Lake
12	Scarification	Spot	Cont(B&C)	1970	Ignace
13	Scarification	Spot	Cont(B&C)	1974	Kenora
14	Scarification	Spot	Cont(B&C)	1981	Dryden
15	Scarification	Spot	Cont(B&C)	1983	Fort Frances
16	Scarification	Spot	Cont(B&C)	1984	Thunder Bay
17	Aerial	Broadcast	Cont(B&C)	1974	Ignace
18	Aerial	Broadcast	Cont(B&C)	1976	Dryden
19	Aerial	Broadcast	Cont(B&C)	1978	Atikokan
20	Aerial	Broadcast	Cont(B&C)	1978	Sioux Lookout
21	Aerial	Broadcast	Cont(B&C)	1981	Red Lake
22	Aerial	Broadcast	Cont(B&C)	1981	Fort Frances
23	Aerial	Broadcast	Cont(B&C)	1982	Dryden
24	Aerial	Broadcast	Cont(B&C)	1984	Red Lake
25	Aerial	Broadcast	Patch	1979	Kenora
26	Aerial	Broadcast	Patch	1986	Ignace
27	Fire	Broadcast	Fire	1974	Kenora
28	Fire	Broadcast	Fire	1980	Thunder Bay
29	Fire	Broadcast	Fire	1980	Thunder Bay
30	Fire	Broadcast	Fire	1983	Red Lake
31	Fire	Broadcast	Fire	1984	Thunder Bay

* Cont = Continuous furrows.

** B&C = Barrel and chain drags.

mineral soil exposed by scarification (Roe 1949, Winston and Sneider 1977). Scarification using drags or blades to redistribute cone bearing slash onto freshly exposed mineral soil is a very common seeding method (Cayford 1970, Smith 1980). Another common seeding method is to aerially sow 50,000-100,000/ha seeds onto snow-covered cutovers treated the previous year by scarification equipment that exposes mineral soil (Riley 1980). These artificial seeding methods were compared to a control of sample areas arising from wildfires.

It may be argued that the scarification seeding method could be classed as having a broadcast seeding dispersal pattern. Slash bearing cones are scattered by the action of the heavy scarification equipment onto freshly made mineral soil furrows. Although the cones can thus be considered to have a broadcast pattern, as the cone scales reflex, seed falls in a spot pattern. For this reason the scarification seed dispersal method was grouped as having a spot seed dispersal pattern.

Three site preparation patterns of exposed mineral soil were related to the seeding methods. Fire creates broad continuous areas of suitable seedbeds. Drag scarifiers (Smith 1980) create parallel continuous furrow patterns with net mineral soil exposures of 18-25%. The intermittent scalping action of the Bracke scarifier creates patch patterns with net mineral soil exposures from 8-13% depending upon the inter-row spacings used. The effect of patterns of site preparation is confounded with the effect of seeding methods on the spatial arrangement of jack pine seedlings.

Sample Design

Road access alongside a selected sample area was divided into approximately 40 units from which a random starting point was selected. A random compass bearing was then adjusted to ensure the direction of travel allowed for sampling within stand boundaries. Sets of 160-200 m transects of 2 x 2 m square plots spaced 20 m apart followed the bearing. Typically, 32 plots per sample area were established.

A working definition for a clump was pivotal to this study. Two approaches were used. The first approach used a subjectively based definition of a "tight" clump as a sample unit from which various measurements could be taken. These clumps were termed tight clumps to distinguish them from dimensionless aggregations. The second approach used Pielou's Index (Pielou 1960) to objectively define the clumpiness of a population of trees.

After two days of viewing candidate sample areas, a tight clump was defined as having the following subjective and objective attributes:

1. Common origin and year of germination, and only Pj trees in the clump.

2. Intraspecific competition and proximity to unstocked areas causing a vertical departure of growth i.e. causing trees to lean out from clump centre.

3. Clump radius (measured at 1 m above ground) of one half the distance between two opposing trees along the clump's perimeter was smaller than three times the diameter of the dominant seedling's stem measured 15 cm above ground level (Fig. 2).

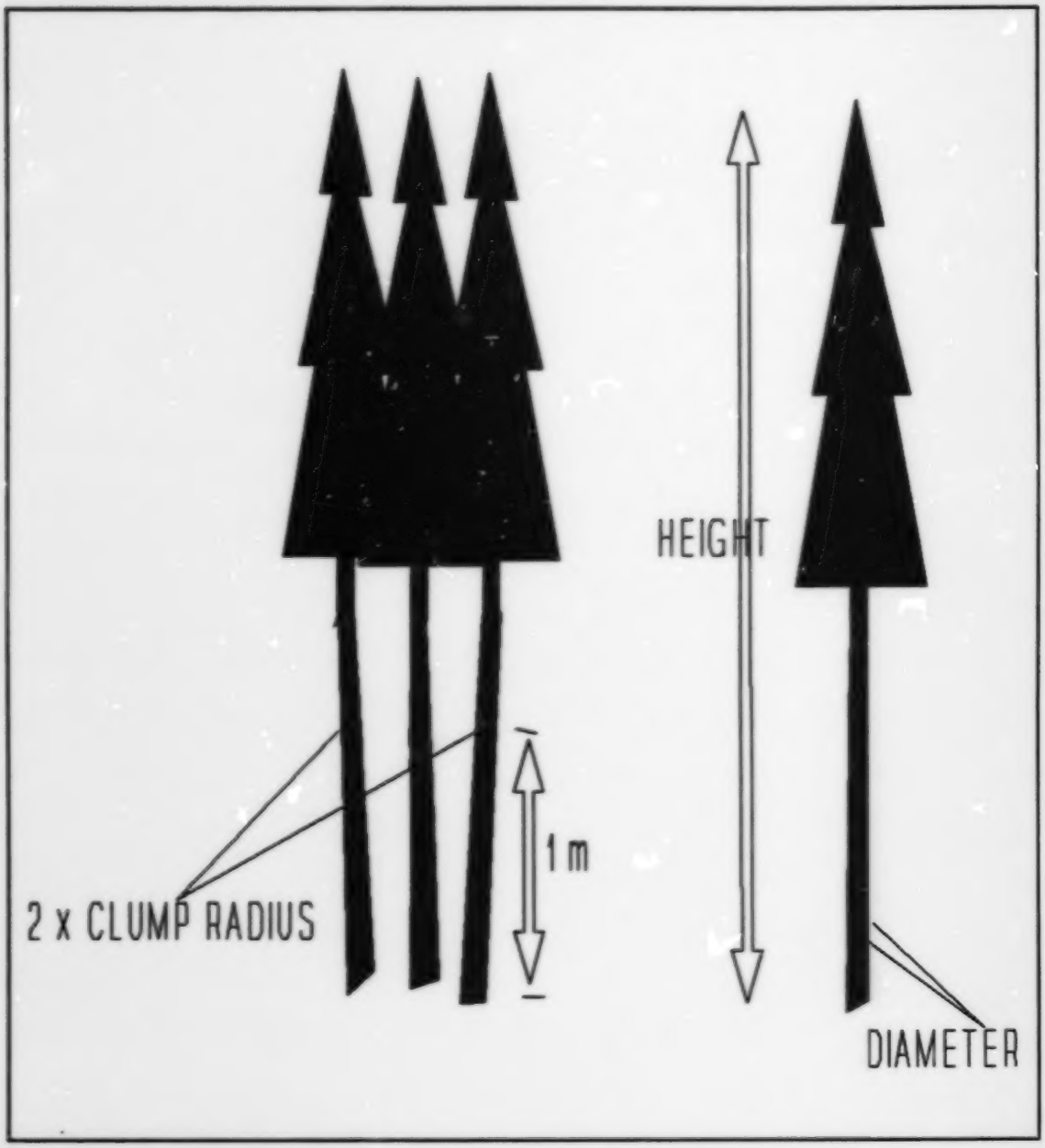

Figure 2 Diagram of stem and clump variables

Tight clumps were only questionable in areas of high density and thus were measured for compliance using (3) above. The subjective approach has merit when one considers that subjective observations of foresters were responsible for the terms of reference for this study. This definition helps eliminate bias between field technicians. Two individuals, a forester and a forest technician, completed the field work for this study and found the above definition workable.

Pielou's non-randomness index (Pielou 1960) was employed in the second approach. It is considered by many to have the greatest utility in describing the spatial arrangement of plant populations (Payandeh 1970). Although more powerful spatial analysis techniques are available (Cliff et al. 1975, Diggle 1983), Pielou's Index was simple, easy to apply and thus fitted more closely with the exploratory nature of this study.

Total number of jack pine seedlings in tight clumps and free growing outside of clumps was recorded at each plot. Free growing refers to any tree not growing within a clump for the purposes of this study. Percent cover of tree, shrub, herb and moss layers was also recorded. Point centre distance, taken from the transect and plot boundary intercept to (i) clump centres and (ii) the nearest free growing jack pine, was measured at every second plot. The tallest tree in the clump and the free grown tree selected bythe point centre distance method were measured for total height (cm). Stem diameter (mm) taken 15 cm above ground level was also recorded. Sample trees were subjectively scored for tree form and

vigour. Most desirable was scored as a 1 and least desirable was scored as a 4. The most influential damaging agent was also scored from 1 to 9 (Appendix 1). Descriptive variables for the sampled clump included clump radius as defined above and number of trees per clump.

Initial data screening and analysis on an IBM personal computer was followed by final analysis on SPSSX software (SPSSX 1988) on Lakehead University's Mini Vax mainframe computer.

Density (stems/ha) and stocking (Chaudhry 1981) of clumped and free growing jack pine seedlings were calculated from the fixed 2 x 2m plot data set. Fairweather and Amrhein (1989) have demonstrated that this method is less biased then deriving density estimates from point centre to nearest plant distance measures. Density of clumps (stems/clump) was also derived from the plot data sets. Pielou's Index was calculated from this data set. A clumping index (CI) was derived as the ratio of the number of trees within clumps to the total number of trees per hectare.

Analysis of variance (ANOVA) was used to test for differences between seeding methods and site preparation patterns. For each variable, the one way unbalanced ANOVA with 25 degrees of freedom in the error term was followed by Tukey's test of ranked means (Steel and Torrie 1980). Least squared linear regression was used to test for correlation of age and other stand level variables with one another.

The full data set was pooled for all seeding methods to derive mean and variance of height and diameter for clumped and free growing trees. Discriminant analysis (Norusis 1988) was used to test for the ability of tree form or other variables to discriminate between free growing or clumped trees. Frequency diagrams were also produced for vigour, form and damage codes for clumped and free growing sample trees.

RESULTS

Stand Attributes

Table 2 lists the more important sample area attributes by seeding method. These attributes were found not to be correlated to stand age (r^2 value ranged from .04 to .22 where n = 31). Although tree density is age dependent within a given stand (Harper 1977) the different site preparation patterns, seed dispersal patterns and other site characteristics make the relatively narrow age class (2-20 years) in this study become quite insignificant as a factor influencing stand density.

Sample areas originating from wildfire produced the highest jack pine density, averaging 25,000 stems/ha. Wildfire density was double that of the scarification method (11,000 stems/ha) and more than triple the density of the other methods. ANOVA found these differences to be significant although sample variances were large enough such that wildfire and scarification were not significantly different from one another (Table 3).

Table 2. Sample area attributes by seeding method.

Sample Area #	Seed Dispersal Method	Density (st/ha)	Clump Density (#/ha)	Clump Index (%)	Trees per Clump	Clump Radius (cm)	Pielou Index	# of Plots
1	Shelter Cones	4688	1016	50	2.87	6.67	2.68	32
2	Shelter Cones	7734	1016	48	3.77	1.77	3.65	32
3	Shelter Cones	8833	1583	55	3.36	4.00	2.47	30
4	Bracke	4500	1000	54	3.15	18.00	2.24	30
5	Bracke	5000	1172	69	2.29	8.86	3.58	32
6	Bracke	15658	2039	39	2.63	6.68	2.58	38
7	Bracke	3750	417	22	2.44	5.67	3.30	30
8	Hand	2266	234	21	2.33	13.78	4.02	32
9	Hand	6563	1016	32	2.50	9.81	4.47	32
10	Hand	5703	703	36	3.00	7.31	2.09	32
11	Hand	7109	859	40	2.92	7.62	3.62	32
12	Scarification	6083	500	16	2.47	6.80	1.96	30
13	Scarification	12813	1875	41	2.46	7.00	5.79	32
14	Scarification	11797	1484	32	2.81	7.50	2.01	32
15	Scarification	9297	938	24	2.43	7.71	2.98	32
16	Scarification	17431	1806	33	2.56	7.25	2.45	36
17	Aerial	11172	859	17	2.19	6.38	3.59	32
18	Aerial	7578	625	19	2.25	7.83	6.30	32
19	Aerial	4750	250	11	2.17	8.50	2.17	30
20	Aerial	3359	156	9	2.25	7.50	1.80	32
21	Aerial	14219	234	3	2.06	8.44	1.86	32
22	Aerial	5469	781	37	2.30	7.10	3.83	32
23	Aerial	13281	1563	29	2.46	6.31	1.79	32
24	Aerial	5859	469	17	3.20	6.27	1.79	32
25	Aerial	3906	391	20	3.00	8.90	3.84	32
26	Fire	3833	333	13	2.38	4.50	1.88	30
27	Fire	7422	234	6	2.00	5.00	6.17	32
28	Fire	8250	813	20	2.17	12.08	2.51	40
29	Fire	43056	2847	15	2.08	7.25	1.48	36
30	Fire	41016	1719	8	2.20	5.07	2.42	32
31	Fire	23690	2440	24	2.28	5.44	1.78	42

Table 3. Ranked means of total seedling density (stems/ha) for each seeding method underscored by lines defining homogenous groups based upon Tukey's test.

Hand	Hand/Shelter	Bracke	Aerial	Scar.	Fire
5410	7085	7227	7342	11,484	24,687
1----------	----------	----------	----------	----------1	
				1----------	----------1

Despite the wide range of densities, stocking was greater then 70% in all cases. (In part, this is a result of the sample design requirements limiting candidate areas to those having $\geq$ 60% stocking). Thus, although hand seeding produces 5,000 stems per hectare compared to fire at 25,000 stems per hectare (Table 3), potential growing space is being effectively utilized by both methods.

All sample areas showed significant levels of clumping based upon Pielou's Index (Table 2) [where < 1 = random, 1 = uniform, and > 1 = aggregated]. Seeding method and site preparation pattern did not affect the level of aggregation. However, ANOVA's using variance parameters like Pielou's Index instead of measured variables can give misleading results. Pielou's Index does not take into account the explicit definition of spatial arrangement used to define tight clumps in this study. Pielou's clumping values refer to patterns of aggregation that are much less specific than those investigated here. It is likely that no other distance/density dependent measure of non-randomness would be any

more effective then Pielou's Index in achieving the objective of this study.

Density of tight clumps of jack pine seedlings averaged 1,072 clumps/ha and was not statistically related to seeding method. However, the ratio of seedlings in clumps to total seedlings per hectare (CI) was strongly affected by seeding method based upon ANOVA results (Table 4).

Spot seeding methods and patch scarification patterns create very high CI values (Table 4) which are associated with high levels of visible clumping. This supports field observations that associate these practises with abundant tight clumps. Our observations show that these clumps are persistent, even after crown closure as shown in sample area #4, the 20-year-old Bracke stand (Table 2).

Results clearly show that all artificial seeding methods create stands that are more clumped in appearance than natural fire origin stands. Patch scarification and spot seeding patterns amplify this phenomenon.

Table 4. Ranked means of CI (%) for each seeding method underscored by lines defining homogenous groups based upon Tukey's test.

Fire	Aerial	Scar.	Hand	Bracke	Shelter Cones
15	17	29	32	46	51
		1----------			----------
1					
1----------	----------1				

ANOVA results show seeding method does not affect the tight clump radius but does affect the number of trees per clump (Tables 2 and 5). Spot seeding patterns, especially hand/shelter methods create denser clumps than the broadcast seed dispersal patterns.

Table 5. Ranked means of the number of trees per clump for each seeding method underscored by lines defining homogenous groups based upon Tukey's test.

Fire	Aerial	Scar.	Bracke	Hand	Shelter Cones
2.1	2.4	2.5	2.6	2.7	3.3
				l----------	----------
l					
l----------	----------	----------	----------	l	

The high hand/shelter clump density may be related to the effectiveness of the shelters. The sample design called for measuring the closest tight clump regardless of whether or not a seed shelter was visible. Sample areas were two to four years old and shelters were still easy to detect. Data were recorded separately for the closest seed shelter to point centre but these were not pooled with the other data sets for the ANOVA of seeding method. The average number of seedlings per shelter cone was found to be 2.9 but this average grew to 3.3 when all clumped seedling data were combined.

Comparisons between seedlings found within shelter cones to trees outside of shelters were quite meaningless. Two of the three shelter cone sample areas were "fill-in" operations of past treatments which failed to achieve adequate stocking. This may have contributed to the poor correlation of age to the population density variables examined in this study. For this reason, the closest tight clump regardless of origin was used in the analysis. Resulting clumping index values are not compromised but some of the growth data would have higher than expected variance caused by the delay between site preparation and regrowth of naturals and the subsequent placement of seed shelters.

Stem Quality

High frequency of clumped trees and higher number of trees per clump in jack pine stands that are not of fire origin can be cause for concern especially in patch site preparation and spot seeding areas. However, comparison of dominant seedlings within a clump against randomly selected trees not growing in clumps revealed that dominant trees found in clumps exhibited superior growth habits. Discriminant analysis showed height and tree form code to be the most important variables distinguishing free growing from clumped trees. The discriminant function was weak, however, with low predictive value.

Clumped trees averaged 63 cm taller and 7 mm larger in diameter than free growing trees. A T-test (Steel and Torrie 1989) showed the height differences to be significant but this was not the case for diameters (Figure 3). Although the differences between diameters and heights would appear to be of the same order of magnitude in Figure 3, their variances are different. Diameters were much more variable than heights showing a co-efficient of variation two times that expressed for height (140% vs. 70%).

These results are somewhat puzzling because one would assume clumped trees should be suppressed through intraspecific competition within the clump and exhibit smaller diameters (Harper 1977). Tree populations classically show an inverse relationship between individual diameter and population density.

We observed that clumped trees tended to occupy the more favourable microsites, largely because spot seeding dispersal methods target these microsites. By our definition, tight clumps exhibit vertical departure from growth (i.e., lean outwards somewhat from the clump centre), a characteristic of clusters of trees surrounded by fairly large openings. Trees in tight clumps had often more direct sunlight compared to single free growing trees which could be shadowed by competing hardwoods.

When suppressed (code #8) free grown trees were removed from the data set, mean height and diameter did increase but not by an appreciable amount. Code #8 was only used for acute suppression and thus more subtle suppression would not be accounted for by our methods.

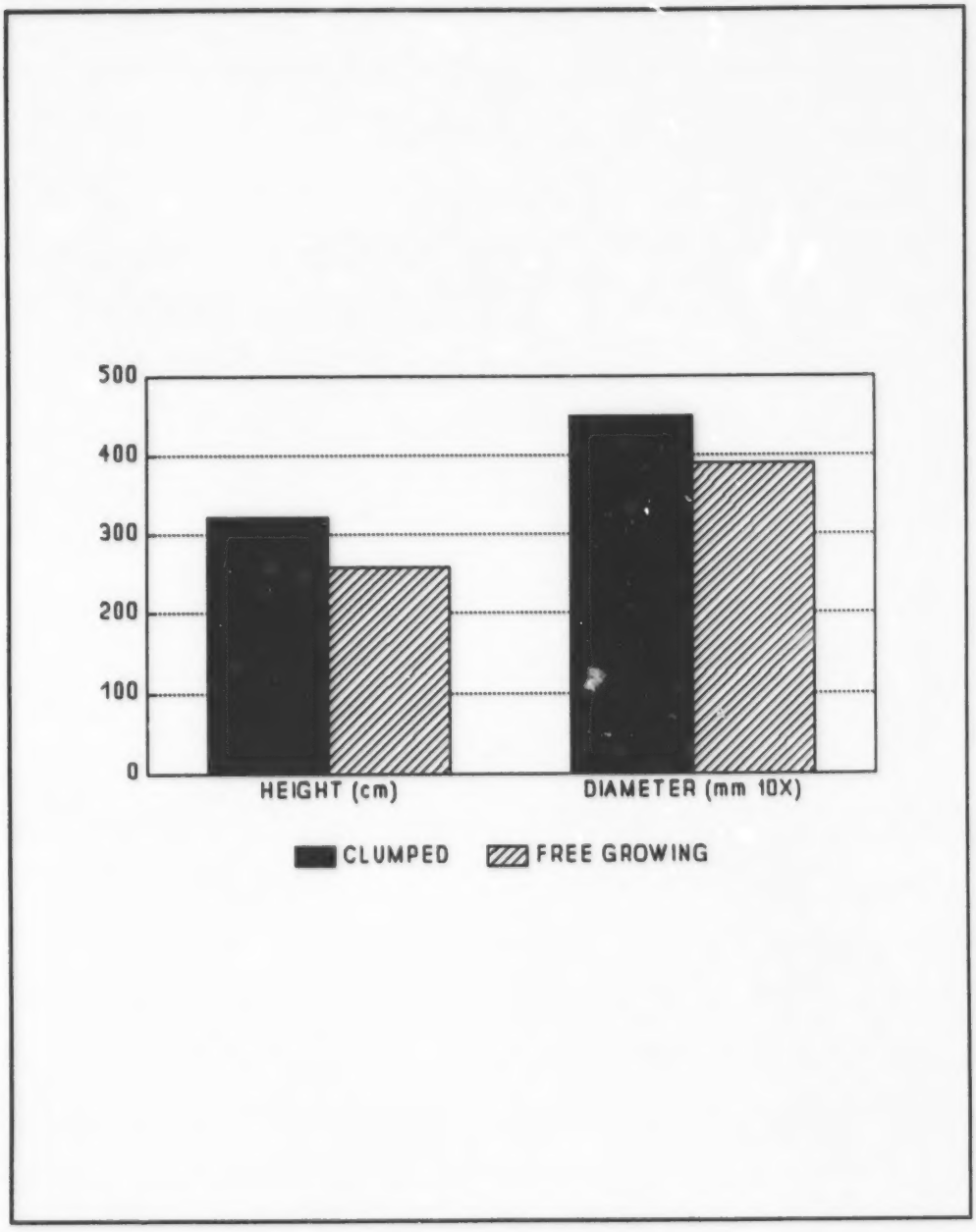

Figure 3. Histogram of sample tree height and diameter for clumped and free growing trees.

Figures 4 to 6 show the clumped trees to exhibit better form and vigour compared to free growing trees. Better form of clumped trees suggests that a clumped environment may control jack pines' tendency toward heavy branching and susceptibility to insect and disease attacks in open areas. Neighbours within clumps may offer mutual protection against damaging agents but do not compete for light, water, or nutrients at the pre-closure phase of stand development. Although, crown dimensions were not recorded, crowns were observed to be asymmetrical within some clumps.

DISCUSSION

Seeding method, dispersal pattern and site preparation pattern can influence initial tree density. Wildfire produced the most dense condition of all the seeding methods examined (25,000 stems/ha).

Roe and Stoeckeler (1950) noted dense jack pine stands of similar densities were susceptible to snow damage. We did not observe this problem in our sample areas originating from wildfire. Standing, fire-killed trees were toppling and killing juvenile pine as they fell. These irregular openings combined with the different snowfall patterns of our boreal forest, compared to the more southern forest described by Roe, may explain why snow damage was absent. The thinning effect of the falling residual stems could help create clumped arrangements of jack pine. Density of tight clumps, however, appears independent of seeding method in our study.

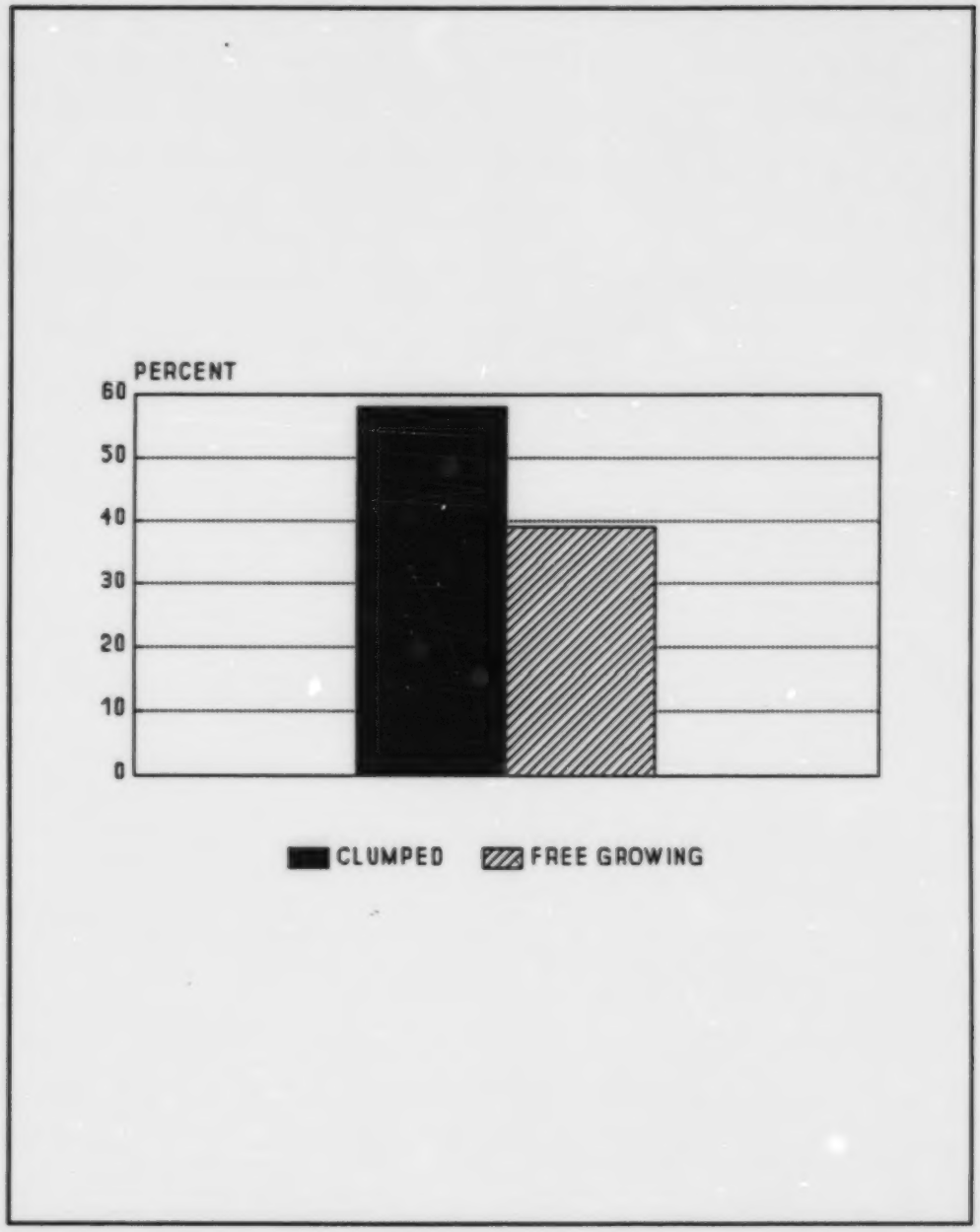

Figure 4. Histogram showing the relative proportion of defect free trees that were free growing or dominant within a clump.

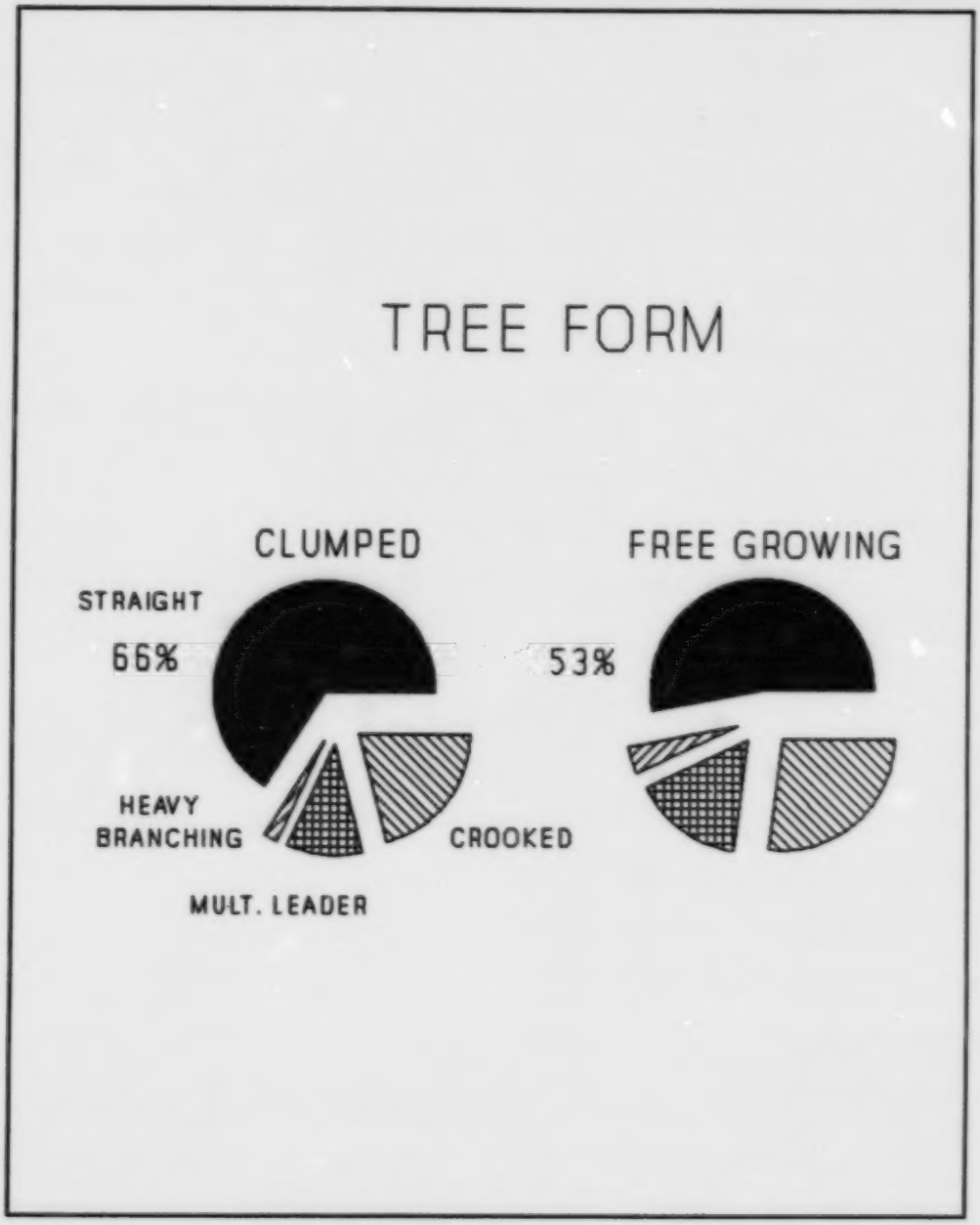

Figure 5. Proportion of tree form classes for each sample tree type.

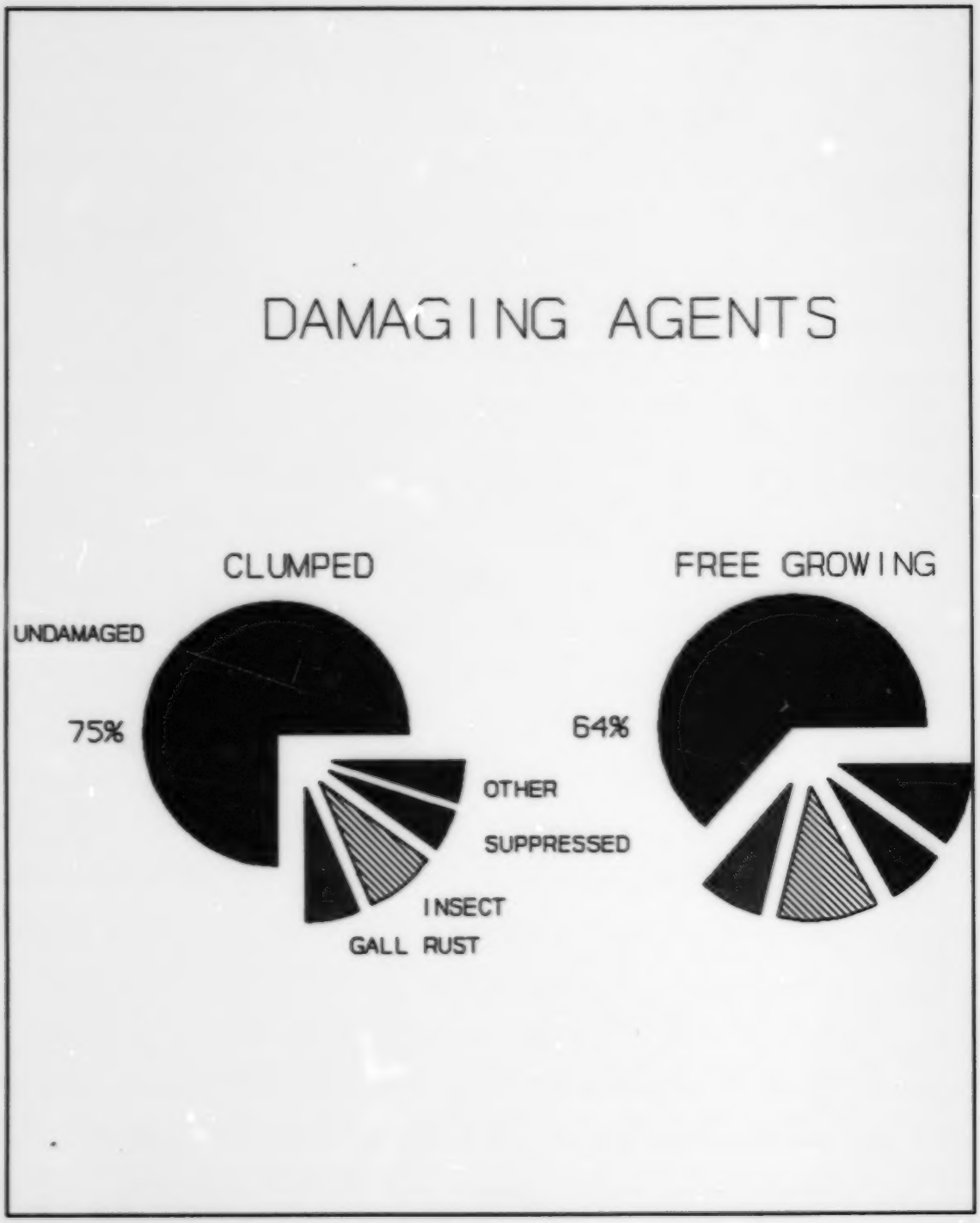

Figure 6. Proportion of damaging agents for each sample tree type.

Chrosciewicz (1971) compared two bladed strips. One strip was treated by scattering slash in patterns which imitate the scarification seeding method examined in this study. The other strip was broadcast sown to imitate wildfire settings. The broadcast sown strip, with an extreme density of more than 800,000 stems/ha showed depressed height and diameter growth. Nine years later, serious snow and wind damage was also prevalent. The strip with scattered slash had densities equivalent to the scarified sample areas examined in this study (10,000 stems/ha) and showed excellent growth and stem characteristics.

Many foresters advocate planting jack pine at wide (2 m+) spacings, especially for sawlog production (Smith 1986). Average plant size is inversely proportional to stand density (Harper 1977, Smith and Hann 1984) and is physically limited after crown closure until differential tree mortality occurs. Although total volume of wood produced in stands grown to full maturity is not affected by density, merchantable yield concentrated in fewer stems (low density) shortens technical rotations and increases financial returns (Hamilton and Christie 1975). Unfortunately, planting at wide spacing increases bole taper and branch size. In addition, jack pine trees may be more prone to weevil and gall rust attack at wider spacings. These effects can result in poorer stem form, lower lumber recovery or poorer pulp yields (Magnussen and Yeatman 1987). Few foresters can agree on optimum jack pine initial spacings for plantations.

Janas and Brand (1988) compared low density jack pine plantations to wildfire jack pine stands and found stem quality of planted trees to be inferior despite superior merchantable volume. Their work led them to conclude that pre-commercial thinning of seed origin stands established at moderate densities (10,000 stems/ha) should produce a combination of stem growth and quality superior to wide spaced plantations (540-2,000 stems/ha). Results of our study suggest that controlling not only density but the spatial arrangement of stems can significantly contribute to an optimum stem growth and quality combination.

An exciting opportunity exists to balance the benefits of stem growth and quality resulting from low density vs. moderate density by having trees arranged in clumps. Ecologists and foresters preoccupied by studies of plant density from 1930 - 1960 are now investigating the spatial arrangement of plants (Pielou 1960, Payandeh 1970, Kenkel 1989). Spatial analysis techniques have become increasingly potent (Diggle 1983) and these techniques show promise in calibrating stand level simulation models. These techniques are also useful when measures of plantation performance are necessary to ensure contractual compliance in new forest tenure arrangements (Brand 1988). Most quantitative studies of the spatial arrangement of trees using these techniques show that conifers originating from seed show highly clumped patterns which give way to relatively uniform distribution at maturity (Ghent and Franson 1986, Kenkel 1989).

Daniels (1978) studied the spatial patterns of 40, 5 to 12-year-old loblolly pine stands of seed origin. All stands showed clumped patterns using Pielou's Index and the degree of clumpiness was not associated with regeneration method. This matches our findings where ANOVA of Pielou's Index showed no significant differences between seeding methods although all sample areas showed high levels of aggregation of trees. However, non-randomness tests like Pielou's describe only departures from randomness, with no specific definition or threshold levels for a tight clump. The subjective definition of a tight clump used for this study more closely addresses the concern that foresters have regarding the prevalence of clumps in spot seeded areas.

Our data clearly show that spot seeding methods create distinct clumps that are persistent for up to 20 years. Although the frequency of clumps is independent of seeding method, the ratio of clumped trees to total trees per hectare (CI) was highest on the spot seeded areas, thus giving the clumped appearance to these stands.

Dimensions of tight clumps as defined by clump radius were not affected by seeding method. However, the number of stems per clump was highest in the hand/shelter spot seeding method (3.3 trees/ clump). These early hand/shelter seeded areas used crude seed metering devices and high seeding rates. The protective environment for seed germination created by the shelters has proven beneficial to seedling emergence especially in open areas exposed to dry continental type weather patterns (Putman and Zasada 1966,

Dominy and Wood 1986). More accurate seed metering and shelter placing tools are now available. Future stands using this method could be established with the number of trees per clump equivalent to or lower than other spot seeding methods.

The Bracke seeding methods usually prescribe 8-15 seeds per spot (Clark 1984, Sidders 1985). Because the seed is prone to water stress, washing and burial (Van Damme 1988), seedling emergence is relatively poor compared to shelter seeding. This may explain the low number of trees per clump (2.6) associated with this method compared to shelter seeding (3.3).

Given the prevalence of clumping in artificially seeded jack pine areas, the quality and growth of clumped versus open grown trees is an important issue. In a 10-year-old jack pine cutover hand sown at 25 seeds per spot, Roe (1949) observed that tree diameter dwindled and height increased as the number of surviving trees per clump increased. He also noted that maximum height to maximum diameter ratios increased with number of trees per clump, indicating spindly trees. This led him to conclude that a thinning was necessary, negating spot seeding cost savings over planting. Furthermore, he felt increasing the number of spots while lowering seeding rates would also be warranted because better tree growth and form would overcome the increased cost of creating more seed spots. Based upon his small number of observations (n = 24, 13, 4 and 7 for seedlings per spot densities of 1, 2-3, 4-5, 6-9, respectively) the observed range of mean maximum heights (4.3 m - 4.8 m) might show significant differences but the diameter ranges

would not (5.8-5.3 cm) unless the sample variance was essentially nil. This is an unlikely situation.

Roe's data are not compelling but the patterns tend to match observations that show depressed stem diameters as seed number per seed shelter increases (Van Damme 1989). These observations were linked to seedlings within the same shelters, all germinating at approximately the same time. Depressed diameter with increased plant numbers is an expected relationship for pure plant populations (Harper 1977). Our study showed clumped trees to be significantly taller but the diameters were not significantly different than free growing trees. These results agree somewhat with Roe's (1949) findings. Spindliness observed by Roe was less apparent in our study, largely because the number of trees per clump tended to be low (2-3 trees). Mean diameters were actually larger for clumped trees compared to free grown trees in our study.

The taller trees of better form associated with clumps in this study are possibly a result of differential microsites favouring early germination and high vigour of trees on spots targeted by the spot seeding methods. Successful germination on these seed spots results in tight clumps. Vertical departure of growth exhibited by clumps is associated with adjacent openings that tended to provide more sunlight to clumps than the randomly located free growing trees that were sometimes shaded by hardwoods.

Another explanation for the prevalence of taller clumped trees could be intraspecific competition for light by trees in the clump. Although stand level density rarely influences height, the close

proximity of trees in tight clumps could have a competitive effect inducing trees to put on more height growth to "out compete" neighbouring trees.

In addition, free grown trees may have been shorter because they were younger than the clumped trees. Johnstone (1977) found that ingress of lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) continued up to 11 years after scarification in Alberta, and this may occur with jack pine as well. None of the free grown trees were aged in our study.

The sample design biased upward the clumped tree growth data because the largest tree in a clump was selected for measurement. Free growing trees closest to point centre were never rejected in favour of larger or better formed trees. When all free growing trees coded as damaged were removed from the data set only a marginal increase in mean tree size resulted. Co-dominants in a tight clump were never measured but often it was difficult to select a sample tree as being distinctly dominant within the clumps because most were equivalent in size. This observation suggests that the contribution of sample bias to the outcome of this study may be fairly weak. We conclude that despite sample bias clumped trees are as good or better in growth than are free growing trees.

Sample bias introduced in this study could be eliminated in future studies by comparing the largest dominant within a clump to the largest free grown dominant in 50 m^2 fixed plots. Dominants are logical to select or compare because they are likely to survive and be harvested at rotation. Another feature worth examining in

the future would be the attributes of co-dominants within clumps. The hypothesis that co-dominants "intercept" damaging agents could then be tested.

Despite sample bias, the possibility of clumped jack pine providing the benefits to stem form of localized high density without extinguishing light and compromising growth rates deserves serious consideration. Our work suggests the clumped pattern does not adversely affect juvenile growth. But what about the long-term effects of clumped patterns? Stiell (1982) reported that a comparison of thinning 13-year-old red pine plantations in a uniform pattern vs. a pattern of four trees per clump revealed that 15 years later the clumped pattern caused trees to develop asymmetric crowns. Clumped trees were leaning away from one another and the clumped area showed a reduced total merchantable volume per hectare compared to the uniformly thinned area. Initially, clumped trees showed superior form and equivalent size and volume per hectare for the first 10 years. Stiell suggests the high costs associated with maintaining uniform spacing are justified.

It is difficult to compare Stiell's results to our study where the average number of trees per clump is two to three versus his four. The age of our sample areas averages about 10 years and inter-tree spacing within clumps averaged 18 cm. Stiell's red pine plantations had initial inter-tree spacings of 1.8 m assessed 28 years after planting.

We suspect that tightly clumped trees in full stocking situations should eventually give way to single stems per seed spot

in relatively uniform patterns due to differential mortality from self thinning over time (20+ years). This philosophy is in agreement with evidence compiled by Kenkel (1989) through simulation models and observations of natural jack pine stands following wildfire in Elk Lake, Ontario. His study showed that just prior to crown closure trees exhibited a random spatial distribution. After crown closure, mortality occurred in clumps as dominant trees overtook the site in a relatively uniform distribution. His work suggests two phases in stem development; an early scramble phase for soil nutrients and water leading to clumps of suppressed trees which are eventually shaded out in the following phase where trees compete for light after crown closure. The clumped pattern observed in our study may affect the timing between Phase 1 and 2 of Kenkel's model but should not result in stands that differ in their spatial patterns of surviving trees.

Payandeh (1974) calculated Pielou's Index for 13 mature forest stands across northern Ontario, three of which were jack pine stands. Two of the three jack pine stands showed the trees to be arranged in clumps. He suggests that uniform spacings are rare in nature, even in older stands, seemingly in contrast to Kenkel's model. This illustrates a problem with different spatial analysis techniques. Each technique uses different assumptions and different distribution functions as a standard for comparison. Objective measures of clumping must be interpreted with caution. If Payandeh's work is describing natural stands effectively, Stiell's (1978) observations concerning the benefits of uniform

spacing would be achievable only in carefully regulated plantation settings. It would seem that Kenkel's (1989) uniform patterns described for natural jack pine stands may be less strict than the uniform patterns described by Pielou's Index. Intuitively, purely uniform spacings can only be achieved in plantations or subsequent thinning operations.

Three empirical approaches are possible to study long-term effects of juvenile clumping of jack pine. The first would require carefully mapping trees within permanent sample plots (PSPs) to be tracked over a fifty-year period. Many PSPs in the province are designed for inventory rather than modelling purposes and individual trees are not precisely mapped. Ths is the situation with existing PSPs in Ontario. Without this spatial data, clumps cannot be studied.

The second approach would be to establish plots with classic experimental design features testing different seeding rates per seed spot. Unfortunately a forty- to fifty-year period would be necessary to obtain results.

The third approach would be to sample jack pine stands that were harvested along the railway right-of-ways 80 years or more ago and compare these stands to mature wildfire stands. Our results show that all regeneration from seed on cutovers is more clumped than wildfire settings. If this comparative clumpiness remains after 80 years, one could deduce that the difference is due to the early clumping of seedlings. A large sample would be required, however, because of the variability caused by site type, soil

chemistry following fire and climatic effects. These confounding effects may make this study very difficult.

Important management strategies are suggested by the results of this study. Clumping does not appear to cause adverse effects at the juvenile stage. Low density spot seeded stands with clumps of trees are likely less expensive to thin than high density stands (Seymour and Godzik 1985, Needham and Clements 1989). Although individual clumps take care and time to thin, their inter-clump spacing, adjacent openings and above all, lower stand densities allow for much higher production with brush saws. It may be more cost effective to try and control spacing at later stages of stand development rather than at establishment phase (Janas and Brand 1988). Stands left untreated will eventually establish nearly uniform patterns through differential mortality caused by competition for light (Ghent and Franson 1986, Kenkel 1989). It is difficult to predict the precise effect clumping will have upon technical rotations and wood quality.

Foresters' concerns about clumping are primarily intuitive. As a result, ground seeding systems have been developed that use pelleted seed to singulate jack pine seed in sophisticated pneumatic assisted seed metering devices (Van Damme 1988, Seabrook 1989). Expensive seed singulation with associated risks of seed coat damage from metering tools may be unnecessary. Still, seed singulation allows further refinements of spatial patterns to consist of dense rows that may possibly be easier to thin than tight clumps associated with spot seeding patterns. Opportunities

may exist to cut scarification costs by lowering microsite frequency per hectare while elevating seeding rates per spot or furrow to ensure sufficient stocking.

CONCLUSIONS

Artificial seeding methods create stands that are distinctly clumped in appearance compared to wildfire stands. Patch scarification or spot seeding methods amplify this phenomenon which is persistent for up to 20 years. There is little evidence to suggest that stand development and stem quality is negatively affected by clumping patterns. To the contrary, clumps appear to offer the advantages of localized high density effects which improve dominant stem form and reduce incidence of damage without significantly depressing diameter growth. Spot seeding methods also tend to produce lower density stands which will be less expensive to thin compared to broadcast sown artificial or wildfire stands. Truly conclusive and precise measures of the effects of clumping on stand development and wood quality will require long-term studies at considerable cost.

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APPENDIX I

ASCII Files

CLUMP ASCII FILE

Variable	Description
1	Plot Number
2	Total Number of Pj in 2 x 2m square plot
3	Number of Pj clumps in square plot
4	Number of free grown Pj in square plot
5	% cover of dominant tree species for the square plot
6	% cover of dominant brush species for the square plot
7	% cover of dominant herb species for the square plot
8	% cover of dominant moss species for the square plot
9	Distance from point center to nearest clump
10	Number of trees in clump
11	Radius of clump (cm)
12	Height of dominant in clump (cm)
13	Diameter of dominant in clump (mm)
14	Vigour code (1,2,3 or 4)
15	Damage code (1,2,3 or 4)
16	Form code (1 to 9)
17	Distance from point center to nearest free grown jack pine
18	Height of free grown Pj (cm)
19	Diameter of free grown Pj (mm)
20	Vigour code (1 to 4)
21	Damage code (1 to 4)
22	Form code (1 to 9)
23	District code (1 to 9)
24	Treatment code (1 to 7)
25	Year of treatment

CLUMP (CERKON) ASCII FILE

Variable	Significance
1	Plot Number
2	Total Number of Pj in 2 x 2m square plot
3	Number of Pj clumps in square plot
4	Number of free grown Pj in square plot
5	% cover of dominant tree species for the square plot
6	% cover of dominant brush species for the square plot
7	% cover of dominant herb species for the square plot
8	% cover of dominant moss species for the square plot
9	Stocked Cerkon cones in square plot
10	Total Cerkon cones in square plot
11	Distance from point center to nearest clump (cm)
12	Number of trees in clump
13	Radius of clump (cm)
14	Height of dominant in clump (cm)
15	Diameter of dominant in clump (mm)
16	Vigour code (1 to 4)
17	Damage code (1 to 4)
18	Form code (1 to 9)
19	Distance from point center to nearest free grown clump (cm)
20	Height of free grown Pj (cm)
21	Diameter of free grown Pj (mm)
22	Vigour code (1 to 4)
23	Form code (1 to 4)
24	Form Code (1 to 4)
25	Distance from point center to nearest Cerkon origin Pj (cm)
26	Number of trees in clump (if Cerkon is a
27	clump)
28	Clump radius (cm) (if cerkon is a clump)
29	Height (of dominant in clump) (cm)
30	Diameter (of dominant in clump) (cm)
31	Vigour code (1 to 4)
32	Form Code (1 to 4)
33	Damage code (1 to 9)
34	District code (1 to 9)
35	Treatment Code (1 to 7)
	Year of treatment

CODES

Vigour

1 - OK
2 - Moderate stress
3 - Severe stress
4 - Dead

Damage

1 - None
2 - Western gall bole
3 - Western gall branch
4 - Insect
5 - Ungulate
6 - Rodent
7 - Abiotic
8 - Suppressed
9 - Root rot

Form

1 - Straight
2 - Heavy Branching
3 - Multiple leader
4 - Crooked

Treatment

1 - Cerkon
2 - Fire
3 - Bracke Bracke
4 - Bracke Aerial Seeded
5 - Scarification
6 - Hand Seed
7 - Aerial Furrow

District

1 - Kenora
2 - Thunder Bay
3 - Red Lake
4 - Sioux Lookout
5 - Dryden
6 - Atikokan
7 - Fort Frances
8 - Ignace
9 - Manitouwadge